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Fractomechanoluminescence Produced During Impulsive Deformation of III-V Semiconductor

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ABSTRACT

When III-V semiconductor fractured impulsively by the impact of a moving piston, then initially the ML intensity increases linearly with time, attains a pick value I_m at a particular time t_m, and later on it decreases with time. The value of time t_m decreases with increasing value of impact velocity, in which t_m is proportional to logarithm of the inverse of v_o, the value of I_m increases linearly with v_o, and the value of I_T initially increases linearly with v_o and then it attains a saturation value for higher value of v_o.The values of t_m increases with the logarithm of the thickness of crystals and the value of the I_m increases linearly with the area of cross section of the crystals and the value of I_T increases linearly with the volume of the crystals.

Keywords: Fractomechanoluminescence, III-V Semiconductor.

INTRODUCTION

To date, the mechanisms of ML in elemental and III-V semiconductors have not been studied in detail. For the ML excitation in elemental and III-V semiconductors, the following models may be proposed: (i) charging of newly created surfaces, (ii) thermal generation of charge carriers. (iii) recombination of fracture-generated defects, and (iv) formation of crack-induced localized states.

Theory

The rate of generations g_1, g_2 and g_3, of electrons in the conduction band, may be expressed as

$$g_1 = z_1 \frac{dS}{dt} \tag{1}$$

$$g_2 = z_2 \frac{dS}{dt} \tag{2}$$

$$g_3 = z_3 \frac{dS}{dt} \tag{3}$$

The rate of creation of new surfaces is given by (Chandra *et al*. 2012)

$$\frac{dS}{dt} = bZ_0V^{(m+m')}K_0\left(n+n'-n''\right)\frac{v_0}{H}\exp[-\{(\xi+\gamma)t\}]\left[\frac{v_0}{H\xi}\{1-\exp(-\xi t)\}\right]^{n+n'-n''-1} \quad (4)$$

Eqs. (1), (2) and (3) can be expressed as:

$$g_1 = z_1bz_0V^{m+m'}K_0\left(n+n'-n''\right)\frac{v_0}{H}\exp\{-(\xi+\gamma)t\}\left[\frac{v_0}{H\xi}\{1-\exp(-\xi t)\}\right]^{n+n'-n''-1} \quad (5)$$

$$g_2 = z_2bz_0V^{m+m'}K_0\,(n+n'-n'')\frac{v_0}{H}\exp\{-(\xi+\gamma)t\}\left[\frac{v_0}{H\xi}\{1-\exp(-\xi t)\}\right]^{n+n'-n''-1} \quad (6)$$

$$g_3 = z_3bz_0V^{m+m'}K_0\,(n+n'-n'')\frac{v_0}{H}\exp\{-(\xi+\gamma)t\}\left[\frac{v_0}{H\xi}\{1-\exp(-\xi t)\}\right]^{n+n-n''-1} \quad (7)$$

where
b = a constant, Z_0 = proportionality constant, V = volume of crystals
m = an exponent, m' = an exponent, K_0 =a constant, n=an exponent
n' = an exponent, n'' = an exponent, v_0 = initial velocity of piston
H = thickness of the sample,
$\xi = \frac{1}{\tau_r}$ = rate-constant for the relaxation of moving piston
τ_r = time constant for the relaxation of moving piston
and, $\gamma =$ rate constant for the decrease of average surface area produced by the movement of single crack

If ϕ_1, $\phi_2$and ϕ_3 are the rate constants for the recombination of the electrons then we can written as

$$\frac{d\Delta n_1}{dt} = g_1 - \phi_1\Delta n_1 \quad (8)$$

$$\frac{d\Delta n_2}{dt} = g_2 - \phi_2\Delta n_2 \quad (9)$$

$$\frac{d\Delta n_3}{dt} = g_3 - \phi_3\Delta n_3 \quad (10)$$

where $\Delta n_1, \Delta n_2$ and Δn_3 are the changes in the number of electrons in the conduction band and shallow traps, surface states and defect centres an any time t.

$$\frac{d\Delta n_1}{dt} = \frac{z_1bz_0VK_0\,v_0}{H}\exp\{-\xi t\} - \phi_1\Delta n_1 \quad (11)$$

$$\frac{d\Delta n_2}{dt} = \frac{z_2bz_0VK_0\,v_0}{H}\exp\{-\xi t\} - \phi_2\Delta n_2 \quad (12)$$

$$\frac{d\Delta n_3}{dt} = \frac{z_3bz_0VK_0\,v_0}{H}\exp\{-\xi t\} - \phi_3\Delta n_3 \quad (13)$$

If η_1', η_2' and η_3' are the efficiency for the electron-hole radiative recombination for the signals A, B, and C.

$$I_1 = \eta_1'\phi_1\Delta n_1 = \frac{\eta_1'z_1bz_0VK_0v_0}{H(\phi_1-\xi)}\phi_1[\exp(-\xi t) - \exp(-\phi_1 t)] \quad (14)$$

$$I_2 = \eta_2'\phi_2\Delta n_2 = \frac{\eta_2'z_2bz_0VK_0\,v_0}{H(\phi_2-\xi)}\phi_2[\exp(-\xi t) - \exp(-\phi_2 t)] \quad (15)$$

and, $$I_3 = \eta_3'\phi_3\Delta n_3 = \frac{\eta_3'z_3bz_0VK_0\,v_0}{H(\phi_3-\xi)}\phi_3[\exp(-\xi t) - \exp(-\phi_3 t)] \quad (16)$$

For $\phi_1 \gg \xi, \phi_2 \gg \xi$ and $\phi_3 \gg \xi$ Eqs. (14), (15) and (16) can be expressed as

$$I_{1r} = \frac{\eta_1'z_1bz_0VK_0\,v_0\phi_1 t}{H} \quad (17)$$

$$I_{2r} = \frac{\eta_2' z_2 b z_0 V K_0\, v_0 \phi_2 t}{H} \quad (18)$$

$$I_{3r} = \frac{\eta_3' z_3 b z_0 V K_0\, v_0 \phi_3 t}{H} \quad (19)$$

It is evident from Eqs. (17), (18) and (19) that after the fracture I_{1r}, I_{2r} and I_{3r} should increase linearly with time t.

The ML intensity I_m corresponding to the peak of ML intensity versus time curve can be given by

$$I_{m1} = \frac{\eta_1' z_1 b z_0 V K_0\, v_0}{H} \quad (20)$$

$$I_{m2} = \frac{\eta_2' z_2 b z_0 V K_0\, v_0}{H} \quad (21)$$

$$I_{m3} = \frac{\eta_3' z_3 b z_0 V K_0\, v_0}{H} \quad (22)$$

The decay of ML intensity may be expressed as

$$I_{1d} = \eta_1' \phi_1 \Delta n_1 = I_{m1} \exp[-\phi_1(t - t_m)] \quad (23)$$

$$I_{2d} = \eta_2' \phi_2 \Delta n_2 = I_{m2} \exp[-\phi_2(t - t_m)] \quad (24)$$

$$I_{3d} = \eta_3' \phi_3 \Delta n_3 = I_{m3} \exp[-\phi_3(t - t_m)] \quad (25)$$

The ML intensity versus time curve can be expressed as

$$I_T = \frac{bZ_0 V K_0\, v_0}{H} \int_0^\infty \left[\{ \frac{\eta_1' z_1 \phi_1}{(\phi_1 - \xi)} [\exp(-\xi t) - \exp(-\phi_1 t)] + \frac{\eta_2' z_2 \phi_2}{(\phi_2 - \xi)} [\exp(-\xi t) - \exp(-\phi_2 t)] + \frac{\eta_3' z_3 \phi_3}{(\phi_3 - \xi)} [\exp(-\xi t) - \exp(-\phi_3 t)] \} \right] . dt$$

$$I_T = (\eta_1' z_1 + \eta_2' z_2 + \eta_3' z_3) \frac{b z_0 V K_0 v_0}{H \xi} \quad (26)$$

where ξ is given by

$$\xi = \frac{v_0}{H[1 - \exp(-\delta v_0)]} \quad (27)$$

To date, no experimental studies have been made on the impulsive excitation of ML in elemental and III-V semiconductors.

CONCLUSION

When a III-V semiconductors is fractured impulsively by the impact of a moving piston, then initially the ML intensity increases linearly with time, attains a peak value I_m at a particular time t_m, and later on it decreases with time. The value of time t_m decreases with increasing value of the impact velocity, in which t_m is proportional to logarithm of the inverse of v_0, the value of I_m increases linearly with v_0, and the value of I_T initially increases linearly with v_0 and then it attains a saturation value for higher values of v_0.The values of t_m increases with the logarithm of the thickness of crystals and the value of I_m increases linearly with the area of cross-section of the crystals and the value of I_T increases linearly with the volume of the crystals. To date, no experimental studies have been made on the impulsive excitation of ML in elemental and III-V semiconductors.

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